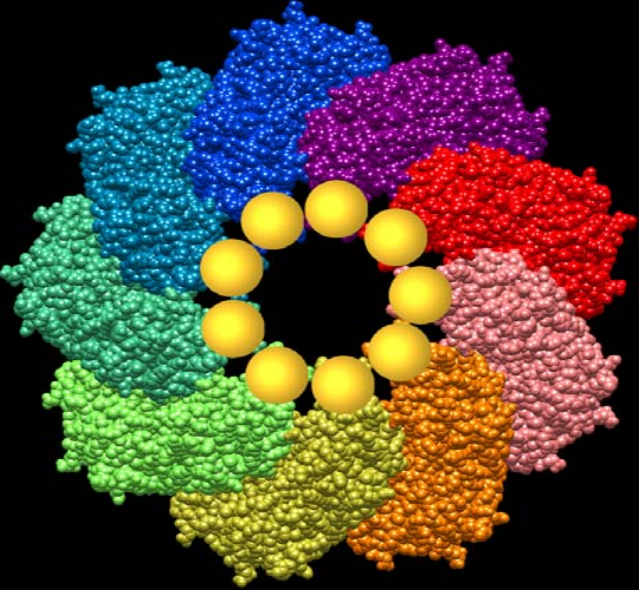


NNI and Manufacturing

Dr. M.C. Roco
Chair, Subcommittee on Nanoscale Science , Engineering and Technology, U.S. National Science and Technology Council
Senior Advisor, NSF, www.nano.gov and www.nsf.gov/nano

- **Defining nanomanufacturing**
- **Four generations of nanomanufacturing**
- **The National Nanotechnology Initiative**
- **Planning for the future**

Manufacturing: Transforming raw materials into products with desired properties and performance – generally in large quantities

Defining Nanomanufacturing (1) :

Aims at building material structures, components, devices/ machines, and systems with nanoscale features in one, two and three dimensions. It includes

- bottom-up directed assembling of nanostructure building blocks (from the atomic, molecular, supramolecular levels),
- top-down high-resolution processing (ultraprecision engineering, fragmentation methods),
- engineering of molecules and supramolecular systems (molecules as devices "by design", nanoscale machines, etc.),
- hierarchical integration with larger scale systems.

Atoms, molecules ⇨ **nanostructure (intermediate)** ⇨ materials/ devices/ machines/ systems

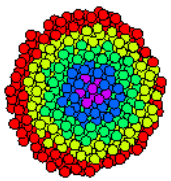
Defining Nanomanufacturing (2)

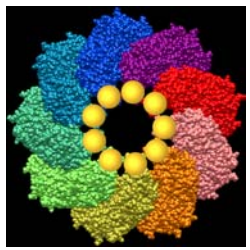
Fragmentation, patterning, restructuring of bulk, ..

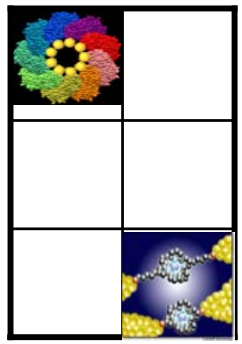
Interfaces, field control, boundary control, integration, ..

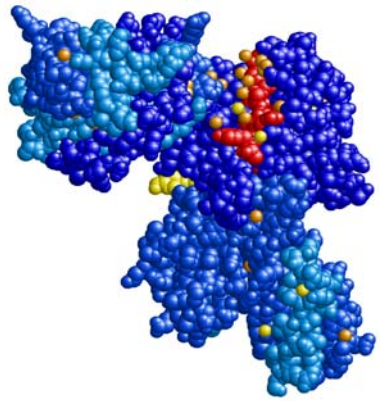
System engineering, device architecture, integration, ..

Nanosystem biology, emerging systems, ..

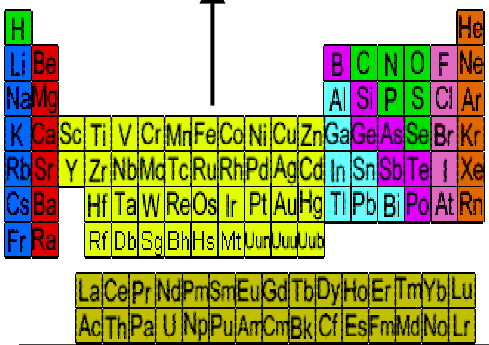








Assembling

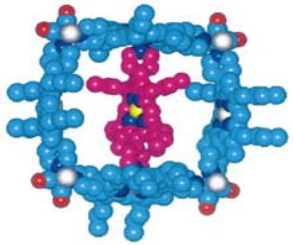


Directed selfassembling, templating, ..

Multiscale selfassembling, in situ processing, ..

Molecules as devices, quantum control, ..

PASSIVE - ACTIVE - HETEROGENEOUS - MOLECULAR NANOSTRUCTURES NANOSYSTEMS



Timeline for beginning of industrial prototyping and commercialization

Accidental nanotechnology: since **1000s yr** (carbon black)

Isolated applications (catalysts, composites, others) since **1990**

Four generations of nanomanufacturing:

- **First Generation: passive nanostructures**
  in coatings, nanoparticles, bulk materials (nanostructured metals, polymers, ceramics):
  ~ 2001 –
- **Second Generation: active nanostructures**
  such as transistors, amplifiers, targeted drugs and chemicals, actuators, adaptive structures:
  ~ 2005 –
- **Third Generation: 3D nanosystems and systems of systems**
  with heterogeneous nanocomponents; complex networking and new architectures
  ~ 2010 –
- **Fourth Generation: molecular nanosystems**
  with heterogeneous molecules, based on biomimetics and new designs
  ~ 2020 (?) -

(M.C. Roco, AIChE Journal, 2004)

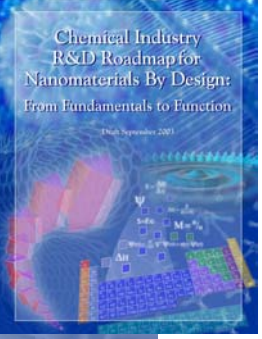
First generation of products: passive nanostructures (~ 2001 –)

- IN PRODUCTION -

- **Goal: Reaching systematic control in passive nanoscale domains, typically for tailoring macroscale properties and functions**

- **Ex. applications:** coatings, nanoparticles, dispersions, nanolayers, sintering, filters, surface nanopatterning, bulk materials - nanostructured metals, polymers, ceramics. Areas of relevance are:
  - Materials
  - Chemicals, including catalysts
  - Pharmaceuticals
  - Electronics

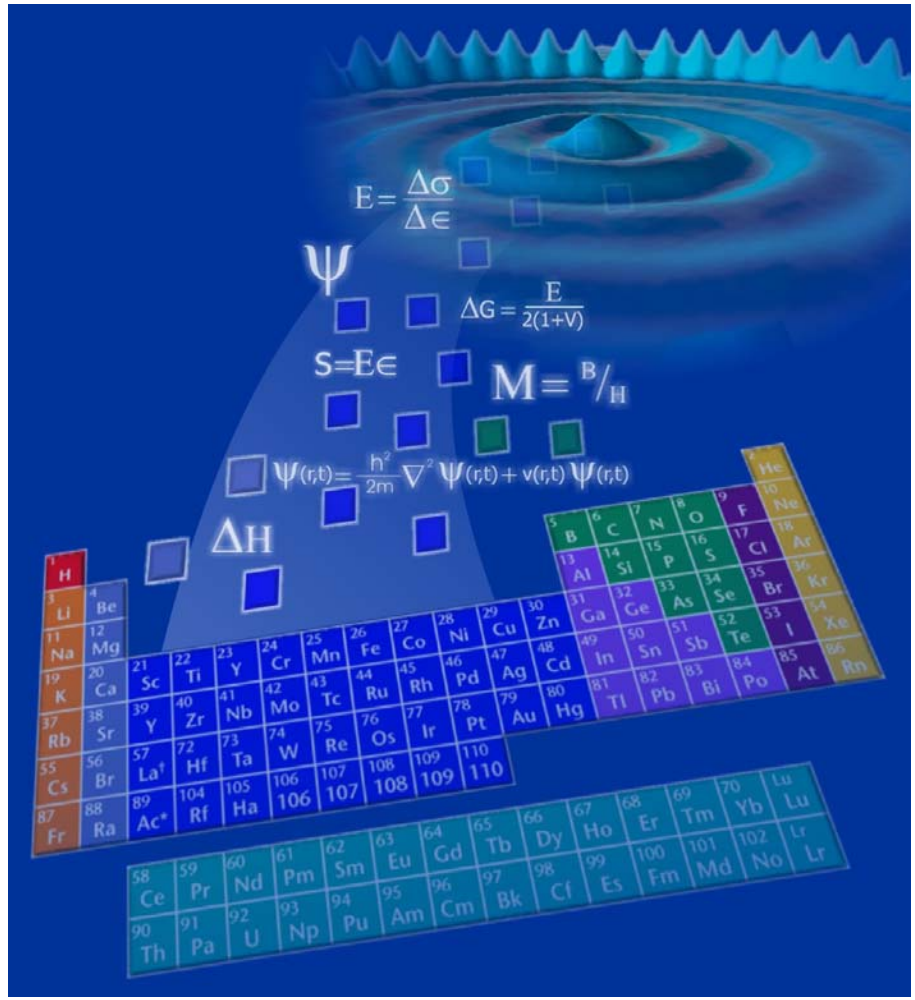
- **R&D focus: on nanostructured materials and tools**
  Ex.: grain boundary simulation, nanomechanics



Nanomaterials By Design

www.ChemicalVision2020.org and NNI

The ability to employ scientific principles in deliberately creating structures with nano-scale features (e.g., size, architecture)
that deliver unique functionality and utility for target applications



Second generation of products: active nanostructures (~ 2005 –)

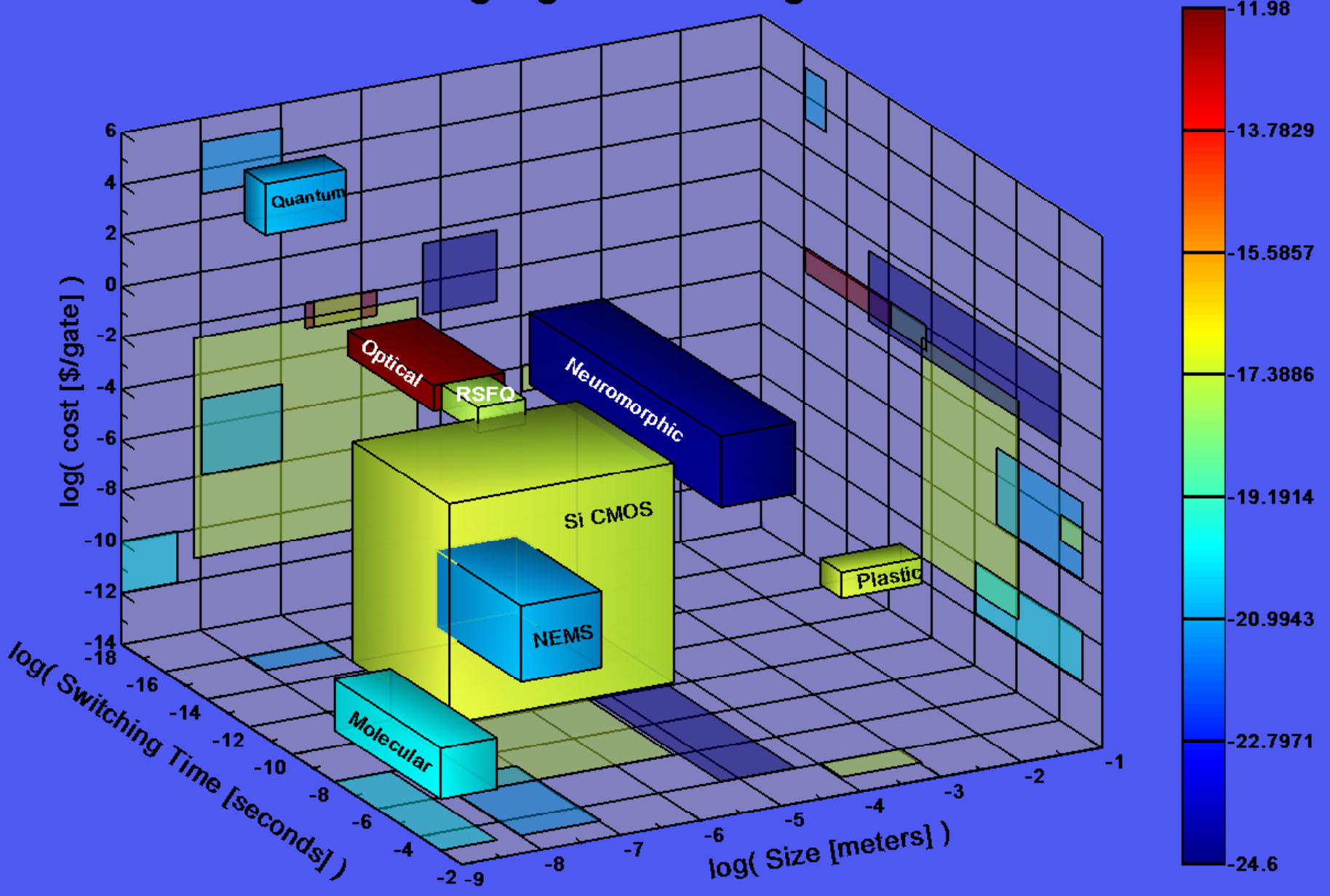
- IN DESIGN -

- **Goal: active nanostructures for mechanical, electronic, magnetic, photonic, biological and other effects, typically for microscale devices and systems**

- **Ex. applications: Targeted drugs, actuators, transistors, sensors, molecular machines, light-driven molecular motors, plasmonics, nanoscale fluidics, various devices. Emerging areas are:**
  - **Nanomedicine**
  - **Energy conversion and storage**
  - **Agriculture and food systems**
  - **Realistic multiphenomena/multiscale simulations**
  - **Environmental applications**

- **R&D focus: novel devices and device system architectures**

Emerging Technologies



Motivation for hybridizing other devices with CMOS (SRC)

Third generation of products: 3D nanosystems and systems of nanosystems (~ 2010 –)

- IN RESEARCH -

- Goal: engineer and manufacture three-dimensional heterogeneous nanosystems, typically for nanoscale components

- Ex. applications: multiscale selfassembling, networking of structures and devices at the nanoscale with new architectures, nanosystems with long scale order, biomedical. Emerging areas are:
  - Nanosystem biology for medicine
  - Nanosystem architectures
  - Realistic multiphenomena/multiscale simulations
  - Environmental bio implications
  - Converging new technologies from the nanoscale

- R&D focus: Design and interaction of supramolecular systems and heterogeneous nanostructures

Fourth generation of products: molecular nanosystems (~2020?)

- IN RESEARCH -

- Goal: heterogeneous molecular nanosystems, typically for nanoscale systems and hybrid bio-assemblies
- Ex. applications: molecules as devices, monitor and condition cells as nanobiosystems, multiscale selfassembled systems, high added value 'smart' or/and adaptive components in larger systems
- R&D focus: atomic/molecular design, collective behavior and chemical-mechanical interaction of molecules, nano-bio-info-cognitive convergence, neuromorphic engineering

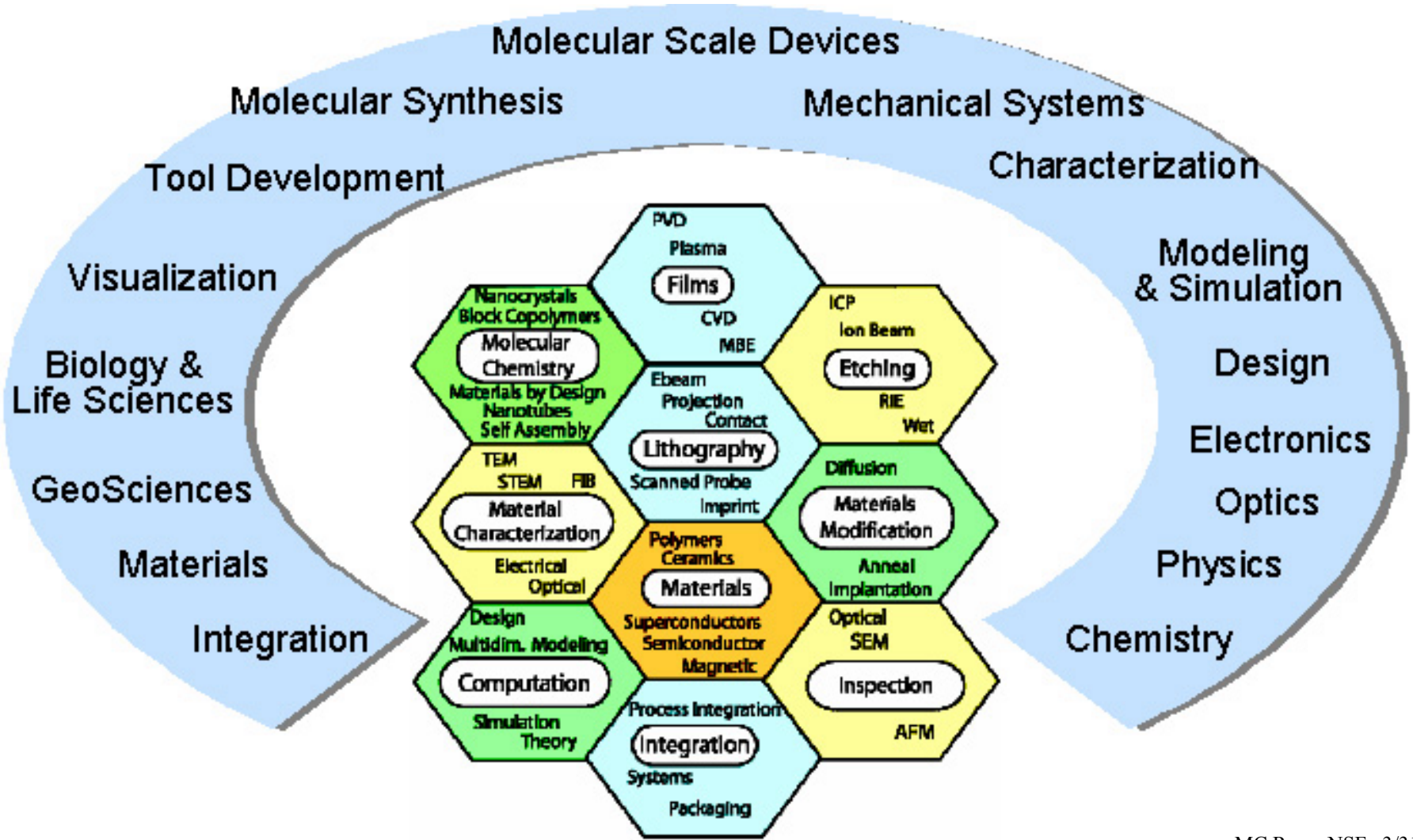
Nanomanufacturing: Several key issues

- Specific nanotechnology processes and equipment; expand on existing infrastructure
- Need for specific instrumentation and metrology
- Integrating length scales in 3-D, time scales, materials, functionality (mechanical, electromagnetic, thermal, biological, chemical) of manufacturing processes; from nanoscale to micro- and macro-scales
- Scaling up / high rate production requirements
- Environmental/Health/Safety requirements and research needs
- Intellectual property issues: time scale, coverage, etc.

NNI and nanomanufacturing 2000 - 2004

- Nanomanufacturing - initial goal of NNI (included in the nanotechnology definition)
- Progressive approach: exploratory research, design, prototyping, applications
- A new NNI Grand Challenge since FY 2002
  Lead agencies: NSF (basics) and NIST (applied)
- About 1/3 NNI budget has relevance to nanomanufacturing (crossing the 5 modes of support)
- Workshops (ex. Report on interagency meeting, 2004)
- Working group focused on nanomanufacturing (12/2003-)
- Evaluations: NRC (Academies), PCAST, OMB/OSTP (PART, GPRA) each agency (COV, Advisory boards)
- Outcomes: R&D, Facilities, SBIR, Partnerships, Growth

NSF National Nanotechnology Infrastructure Network (13 nodes)



DOE Nanoscale Science Research Centers

Summer ‘03

Center For Nanophase Materials Sciences at ORNL

Spring ‘05

Center For Functional Nanomaterials at BNL

Spring ‘04

Molecular Foundry at LBNL

Spring ‘04

Center for Nanoscale Materials at Argonne

Spring ‘04

Center for Integrated Nanotechnologies

Manufacturing at Nanoscale

- challenges -

- Create tailored structures in the 0.1-100 nm range
- Combine top-down and bottom-up approaches
- Integration along scales with larger systems
- Large scale production and economical scale up: different concepts and principles?
- *Interaction non-living and living structures*
- *Replication (ex: lithography)*
  Self-replication (ex: bio, DNA-based)
- *Revolutionary processes envisioned*
  Extend existing manufacturing capabilities if possible